

502/472
(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
7 August 2003 (07.08.2003)

PCT

(10) International Publication Number
WO 03/064844 A1

(51) International Patent Classification⁷: **F02M 25/10, 25/12**

(21) International Application Number: **PCT/US02/02168**

(22) International Filing Date: **25 January 2002 (25.01.2002)**

(25) Filing Language: **English**

(26) Publication Language: **English**

(71) Applicant (for all designated States except US): **WORLD AIR ENERGY CORPORATION** [US/US]; P.O. Box 309, Nixon, TX 78140-0309 (US).

(71) Applicant and

(72) Inventor: **DAVIDSON, James, G.** [US/US]; 3615 Highway 79 North, Paris, TN 38242 (US).

(74) Agent: **MAXWELL, Roger, L.**; Jenkins & Gilchrist, P.C., Suite 3200, 1445 Ross Avenue, Dallas, TX 75202 (US).

(81) Designated States (national): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, OM, PH, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZM, ZW.

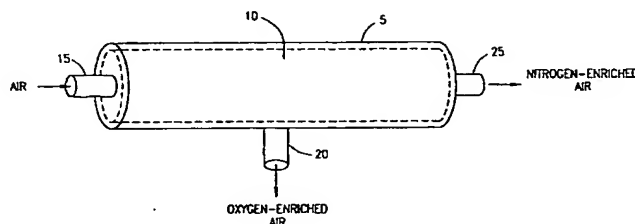
(84) Designated States (regional): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— with international search report

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: **METHOD AND APPARATUS FOR MEMBRANE SEPARATION OF AIR INTO NITROGEN AND OXYGEN ELEMENTS FOR USE IN INTERNAL COMBUSTION ENGINES**



(57) Abstract: A method and apparatus for reducing the emissions and improving the performance of an internal combustion engine (40). An input air stream is separated into an oxygen-enriched air stream and a nitrogen-enriched air stream. The nitrogen-enriched air stream is received by a holding chamber (35). The oxygen-enriched air and a combustible fuel are provided to a combustion chamber (45) of the internal combustion engine (40) and a combustion process is initiated. After a predefined time delay, a volume of nitrogen-enriched air is provided from the holding chamber (35) to the combustion chamber (45) to be used during the rest of the combustion process.

WO 03/064844 A1

METHOD AND APPARATUS FOR MEMBRANE SEPARATION OF AIR
INTO NITROGEN AND OXYGEN ELEMENTS FOR USE IN INTERNAL
COMBUSTION ENGINES

5

BACKGROUND OF THE INVENTION

Technical Field of the Invention

This invention relates to a method and system for
reducing emissions and improving performance of an
internal combustion engine by providing oxygen-enriched
air and nitrogen-enriched air to a combustion chamber.

Description of Related Art

The purpose of an internal combustion engine is to
convert the chemical energy of fuel into the mechanical
energy of motion using a process of combustion. As is
known, internal combustion engines are used extensively
in a variety of machines including mobile vehicles, or for
other purposes, such as power generation. However,
internal combustion engines produce emissions from the
combustion process which include a number of pollutants
whose presence are undesirable in the environment. As a
result, numerous regulations have been implemented by
various government bodies requiring reductions in these
pollutants. The primary pollutants produced by internal
combustion engines during the combustion process include
oxides of nitrogen (NOx), carbon monoxide (CO),
particulate matter (PM), and hydrocarbons (HC). Nitrogen
oxides (NOx), such as nitric oxide and nitrogen dioxide,
are formed during the combustion process when air combines

-2-

with oxygen under the high temperature conditions of the engine's combustion chamber. Nitrogen oxides contribute to the formation of ozone, smog, and acid-rain. Carbon monoxide is formed during the combustion process from the incomplete combustion of the air-fuel mixture. Carbon monoxide is a colorless, odorless, and toxic gas, and is one of the most dangerous of the combustion process pollutants. Particulate matter is also formed during incomplete combustion and consists of a mixture of solid and liquid matter whose main constituent is carbon. Particulate matter is a major source of visible urban air pollution such as soot and haze. Hydrocarbons are formed from the combustible fuel and lubrication oils and additives used within the engine. Both particulate matter and hydrocarbons are suspected carcinogens. In comparison to gasoline engines, diesel engines have particularly high concentrations of nitrogen oxides and particulate matter contained in their emissions.

It has been known in the past that the introduction of oxygen-enriched air into the combustion chamber during the combustion process allows for more complete combustion and results in a reduction in the formation of particulate matter, carbon monoxide, and hydrocarbons. An increase in fuel efficiency, as well as engine power, can also be achieved through oxygen-enrichment. However, oxygen-enrichment of the combustion process results in an undesirable change in NOx production, as well as an increase in combustion temperatures, which can cause

-3-

engine overheating. An example of an oxygen-enrichment of intake air is described in U.S. Patent Number 5,636,619. The method described in U.S. Patent Number 5,636,619 requires the use of a suitable NOx after-treatment device in the exhaust stream to attempt to reduce the higher level of NOx generated by the oxygen-enrichment. However, U.S. Patent Number 5,636,619 does not offer a solution to the problem of engine overheating caused by oxygen-enrichment of intake air.

10 The introduction of nitrogen-enriched air into the exhaust stream of an internal combustion engine has also been known in the past to reduce NOx present in the exhaust gases. U.S. Patent No. 5,640,845 describes a NOx reduction method which includes the injection of atomic
15 nitrogen into the exhaust gases of an internal combustion engine. However, U.S. Patent Number 5,640,845 also does not offer a solution to the problem of engine overheating caused by oxygen-enrichment of intake air.

20 The present invention provides for a reduction in emission pollutants, as well as increased fuel efficiency and engine power, while reducing or eliminating the disadvantages of prior methods. The introduction of nitrogen-enriched air into the combustion chamber after the start of combustion provides for a reduction in the
25 formation of NOx, while reducing or eliminating the problem of engine overheating caused by oxygen-enrichment of intake air.

-4-

SUMMARY OF THE INVENTION

The present invention comprises a method and apparatus for reducing the emissions and improving the performance of an internal combustion engine. An input
5 air stream is separated at least in part into an oxygen-enriched air stream and a nitrogen-enriched air stream. The nitrogen-enriched air stream is received by a holding chamber. The oxygen-enriched air and a combustible fuel are provided to a combustion chamber of the internal
10 combustion engine and a combustion process is initiated. After a predefined time delay, a volume of nitrogen-enriched air is provided from the holding chamber to the combustion chamber to be used during the rest of the combustion process.

15

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the present invention, reference is made to the following detailed description taken in conjunction with the accompanying
20 drawings wherein:

FIGURE 1 is a membrane 5 for the separation of air into nitrogen and oxygen elements in accordance with the principles of the present invention;

FIGURE 2 is an apparatus 30 for the separation of air
25 into nitrogen-enriched air streams and oxygen-enriched air streams for use in an internal combustion engine in accordance with the principles of the present invention;
and

-5-

FIGURE 3 is a method in flowchart form for the separation of air into nitrogen-enriched air streams and oxygen-enriched air streams for use in an internal combustion engine in accordance with the principles of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Reference is now made to the Drawings wherein like reference characters denote like or similar parts throughout the various Figures. Referring now to FIGURE 1, a membrane 5 for the separation of air into nitrogen and oxygen elements in accordance with the principles of the present invention is illustrated. The membrane 5 functions to separate air directed into the membrane 5 into oxygen-enriched air streams and nitrogen-enriched air streams. The membrane 5 contains an inner membrane material 10, which through a process of selective permeation or solution-diffusion separates the air directed through the membrane material 10 into an oxygen-enriched air stream and a nitrogen-enriched air stream. This process can be accomplished due to the fact that oxygen has a higher solubility through the inner membrane material 10 than that of nitrogen. Typically, the membrane material 10 is composed of a bundle of hollow polymer fibers which selectively allow oxygen molecules to diffuse through the membrane wall while allowing nitrogen molecules to pass through the hollow fibers without being absorbed.

-6-

During operation, an air stream is directed into the membrane 5 through an air input port 15. Oxygen-enriched air is extracted from the membrane 5 through an oxygen-enriched air output port 20 at a negative pressure relative to that of the air at the air input port 15. Nitrogen-enriched air is extracted from the membrane 5 through a nitrogen-enriched air output port 25 at a high pressure relative to that of the oxygen-enriched air. The desired high pressure of the input air stream can be achieved by compressing, by various methods, the air stream prior to providing the air stream to the air input port 15. The purity of the nitrogen-enhanced air stream can be adjusted according to the flow rate, pressure, and temperature of the air stream fed into the membrane 5.

Referring now to FIGURE 2, an apparatus 30 for the separation of air into nitrogen-enriched air streams and oxygen-enriched air streams for use in an internal combustion engine in accordance with the principles of the present invention is illustrated. An input air stream is directed into the air input port 15 of the membrane 5 which separates the air into an oxygen-enriched air stream which is output through an oxygen-enriched air output port 20, and a nitrogen-enriched air stream which is output through a nitrogen-enriched air output port 25. The oxygen-enriched air stream is at a negative pressure relative to the pressure of the nitrogen-enriched air stream. In an example embodiment of the present invention, the oxygen-enriched air stream is at a negative

-7-

pressure of 16 inches, and the nitrogen-enriched air stream is at a pressure of 75 psi. The oxygen-enriched air from the oxygen-enriched air output port 20 is directed into a combustion chamber 45 of an internal combustion engine 40, such as a diesel or gasoline engine, and the nitrogen-enriched air is directed from the nitrogen-enriched air output port 25 into a holding chamber 35. In an embodiment of the present invention, a compressor or blower, such as a turbocharger or supercharger, may be used to increase the pressure of the input air stream before it is directed into the air input port 15 in order to allow the membrane 5 to more efficiently separate the oxygen and nitrogen elements of the air. Although the present embodiment of the invention is illustrated by the use of a membrane, it should be understood that other methods and devices for separating an air stream into oxygen-enriched air streams and nitrogen-enriched air streams could be used.

After the introduction of the oxygen-enriched air into the combustion chamber 45, a combustion process using the oxygen-enriched air and combustible fuel is initiated. The introduction of the oxygen-enriched air into the combustion chamber 45 allows for more complete combustion, produces more engine power, and increases fuel efficiency. In addition, the amount of particulate matter, carbon dioxide, and hydrocarbons present in the engine emissions is significantly reduced.

- 8 -

After a predefined time delay following the start of the combustion process, a predefined volumetric mass of nitrogen-enriched air is released from the holding chamber 35 and directed into the combustion chamber 45 to be used in the remainder of the combustion process. In one embodiment of the present invention, the time delay for the introduction of nitrogen-enriched air is four milliseconds and the predefined volumetric mass of nitrogen is equal to that which gives a volumetric mass in the combustion chamber 45 of ninety percent nitrogen and one percent unknown composition. However, the predefined time delay and predefined volumetric mass of nitrogen-enriched air may be chosen based on a variety of factors including the burn rate of the fuel, the gas composition in the combustion chamber, speed of the engine, etc. In addition, the predefined volumetric mass can be changed continuously according to the operating conditions of the engine 40. Because combustion is already in progress, the nitrogen mass does not convert easily to NO_x. As a result, NO_x emissions are greatly reduced. The reduced emissions provided by the present invention eliminates the need for a catalytic convertor. The introduction of nitrogen also provides for the added benefit of cooling the combustion chamber 45, which produces more engine power per volume of fuel and prevents overheating of the engine 40. Control of the release of the nitrogen-enriched air from the holding chamber 35 can be accomplished through a variety of means including

-9-

injection nozzles, electronic valves, mechanical valves, pumps, etc. After the combustion process is complete, the exhaust emissions are expelled from the combustion chamber 45 through an exhaust outlet 50.

5 In accordance with an alternative embodiment of the present invention, the oxygen-enriched air and nitrogen-enriched air are provided from separate sources, such as storage tanks, without the use of a membrane to separate the oxygen and nitrogen elements from an input air stream.

10 Referring now to FIGURE 3, a method for the separation of air into nitrogen-enriched air streams and oxygen-enriched air streams for use in an internal combustion engine in accordance with the principles of the present invention is illustrated in flowchart form. In
15 step 55, an input air stream is provided to an oxygen and nitrogen separation device. In step 60, the input air stream is separated into an oxygen-enriched air stream and a nitrogen-enriched air stream. In step 65, the oxygen-enriched air stream and combustible fuel are provided to
20 the combustion chamber of an internal combustion engine. Next, in step 70, combustion is initiated using the oxygen-enriched air and fuel mixture. As previously described in reference to FIGURE 2, the introduction of the oxygen-enriched air into the combustion chamber allows
25 for more complete combustion, produces more engine power, and increases fuel efficiency, as well as reduces the amount of particulate matter, carbon dioxide, and hydrocarbons present in the engine emissions. In step 75,

-10-

a volume of the nitrogen-enriched air is provided to the combustion chamber after a predetermined time delay to be used in the remainder of the combustion process, thereby reducing NOx emissions and cooling the combustion chamber.

5 Finally, in step 80, the emissions are exhausted from the combustion chamber. The method is repeated for each cycle of the combustion process.

Experimental results have shown that emissions, such as NOx and carbon monoxide, can be reduced by eighty-two
10 percent using the principles of the present invention. For example, a diesel engine that typically exhausts 2900 pounds of particulate matter per year into the atmosphere is expected to be reduced by 2378 pounds per year by using the principles of the present invention.

15 Although a preferred embodiment of the method and apparatus of the present invention has been illustrated in the accompanying Drawings and described in the foregoing Detailed Description, it is understood that the invention is not limited to the embodiment disclosed, but
20 is capable of numerous rearrangements, modifications, and substitutions without departing from the spirit of the invention as set forth and defined by the following claims.

-11-

WHAT IS CLAIMED IS:

1. A method for the operation of an internal combustion engine comprising the steps of:
providing oxygen-enriched air and fuel to a
5 combustion chamber;
initiating combustion of the oxygen-enriched air and fuel; and
providing a predefined volume of nitrogen-enriched air to the combustion chamber after a predefined time
10 delay to be used during the remainder of the combustion.
2. The method of claim 1, wherein prior to the
step
15 of providing oxygen-enriched air and fuel to a combustion chamber:
providing an input air stream to a membrane; and
separating, using the membrane, an input air stream to produce the oxygen-enriched air and the
20 nitrogen-enriched air.
3. The method of claim 1, wherein the predefined time delay comprises:
substantially four milliseconds.
- 25 4. The method of claim 1, wherein the predefined volume of nitrogen-enriched air comprises:

-12-

substantially ninety-percent of the volumetric mass within the combustion chamber.

5 5. The method of claim 1, wherein the internal combustion engine comprises:

 a diesel engine.

 6. The method of claim 1, wherein the internal combustion engine comprises:

10 a gasoline engine.

 7. An apparatus comprising:

 a separation device for receiving an input air stream and producing oxygen-enriched air and nitrogen-enriched air;

15 a holding chamber for receiving the nitrogen-enriched air from said separation device; and

 a combustion chamber for receiving the oxygen-enriched air from said separation device and a combustible fuel, the combustion chamber initiating a combustion process using the oxygen-enriched air and the combustible fuel, and further receiving a predefined volume of the nitrogen-enriched air from the holding chamber after a predefined time delay to be used during the remainder of the combustion process.

25 8. The apparatus of claim 7, wherein said separation device comprises:

-13-

a membrane.

9. The apparatus of claim 7, wherein the
predefined
5 time delay comprises:
substantially four milliseconds.

10. The apparatus of claim 7, wherein the
predefined
10 volume of nitrogen-enriched air comprises:
substantially ninety-percent of the volumetric
mass within the combustion chamber.

11. The apparatus of claim 7, wherein the holding
15 chamber further comprises:
at least one of an injection nozzle, an electronic
valve, a mechanical valve, and a pump for providing the
desired predefined volume of the nitrogen-enriched air
to the combustion chamber.

20 12. The apparatus of claim 7, wherein the
internal combustion engine comprises:
a diesel engine.

25 13. The apparatus of claim 7, wherein the
internal combustion engine comprises:
a gasoline engine.

-14-

14. An internal combustion engine comprising:
a separation device for receiving an input air stream and producing oxygen-enriched air and nitrogen-enriched air;

5 a holding chamber for receiving the nitrogen-enriched air from said separation device; and
a combustion chamber for receiving the oxygen-enriched air from said separation device and a combustible fuel, the combustion chamber initiating a
10 combustion process using the oxygen-enriched air and the combustible fuel, and further receiving a predefined volume of the nitrogen-enriched air from the holding chamber after a predefined time delay to be used during the remainder of the combustion process.

15

15. The internal combustion engine of claim 14, wherein said separation device comprises:
a membrane.

20

16. The internal combustion engine of claim 14, wherein the predefined time delay comprises:
substantially four milliseconds.

25

17. The internal combustion engine of claim 14, wherein the predefined volume of nitrogen-enriched air comprises:

substantially ninety-percent of the volumetric mass within the combustion chamber.

-15-

18. The internal combustion engine of claim 14,
wherein the holding chamber further comprises:

at least one of an injection nozzle, an electronic
valve, a mechanical valve, and a pump for providing the
5 desired predefined volume of the nitrogen-enriched air
to the combustion chamber.

19. The internal combustion engine of claim 14,
wherein the internal combustion engine comprises:
10 a diesel engine.

20. The internal combustion engine of claim 14,
wherein the internal combustion engine comprises:
a gasoline engine.

15

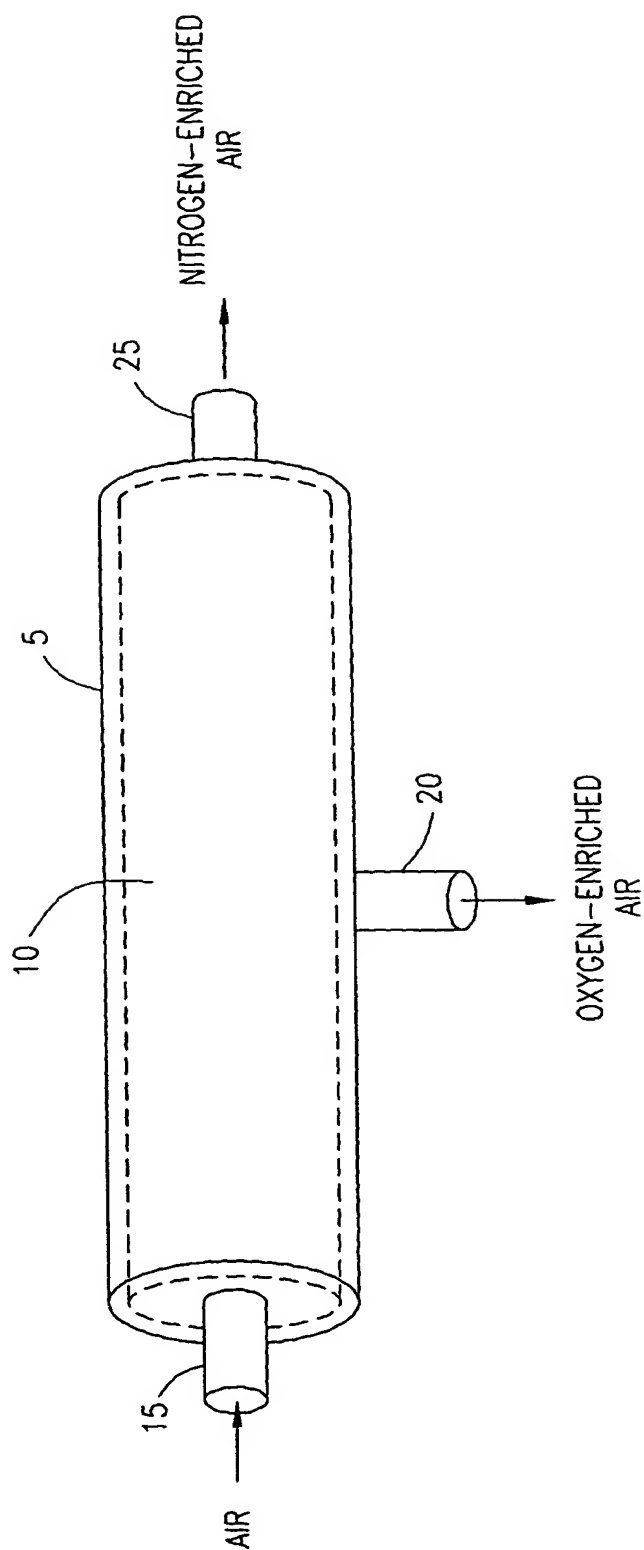


FIG. 1

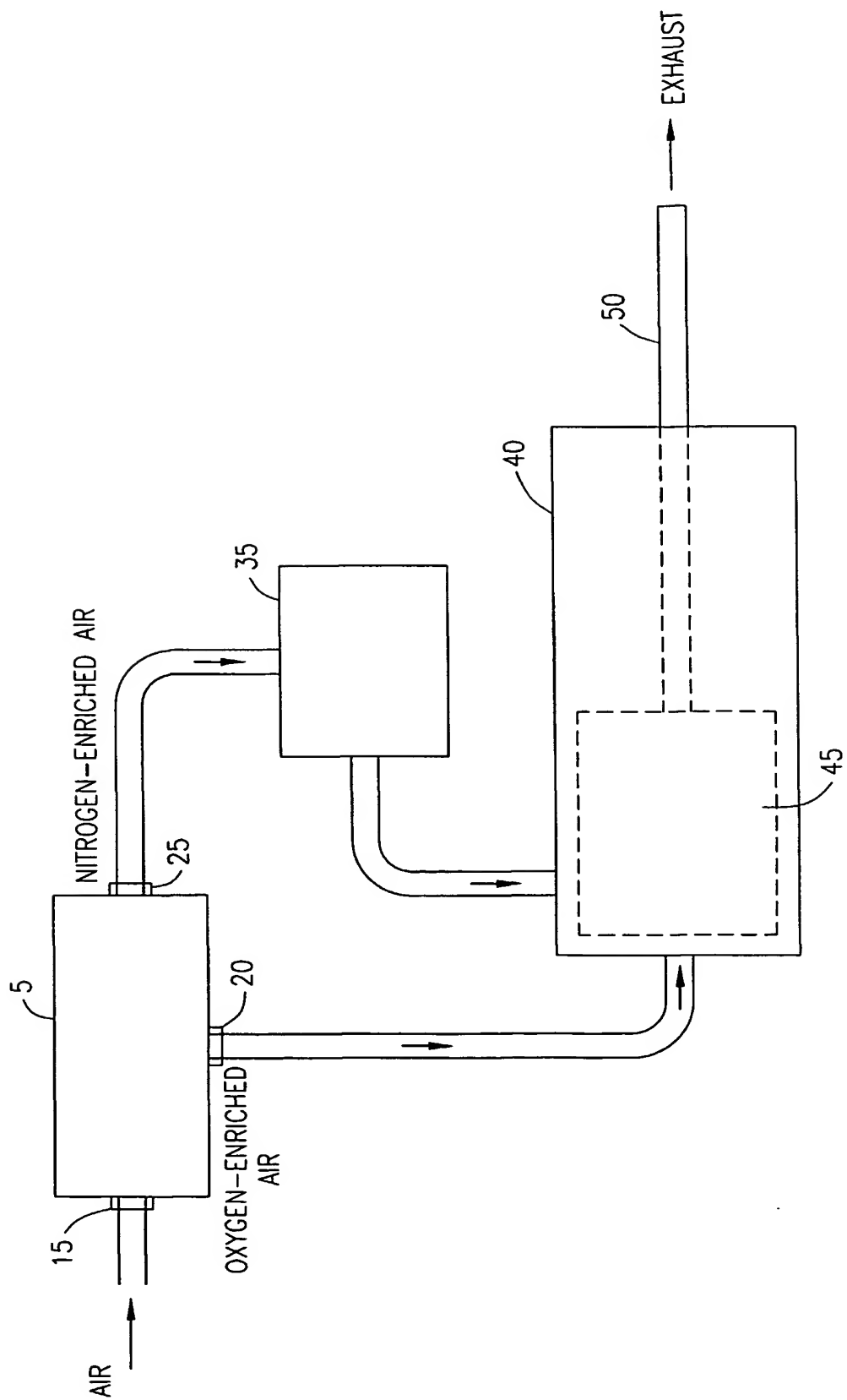
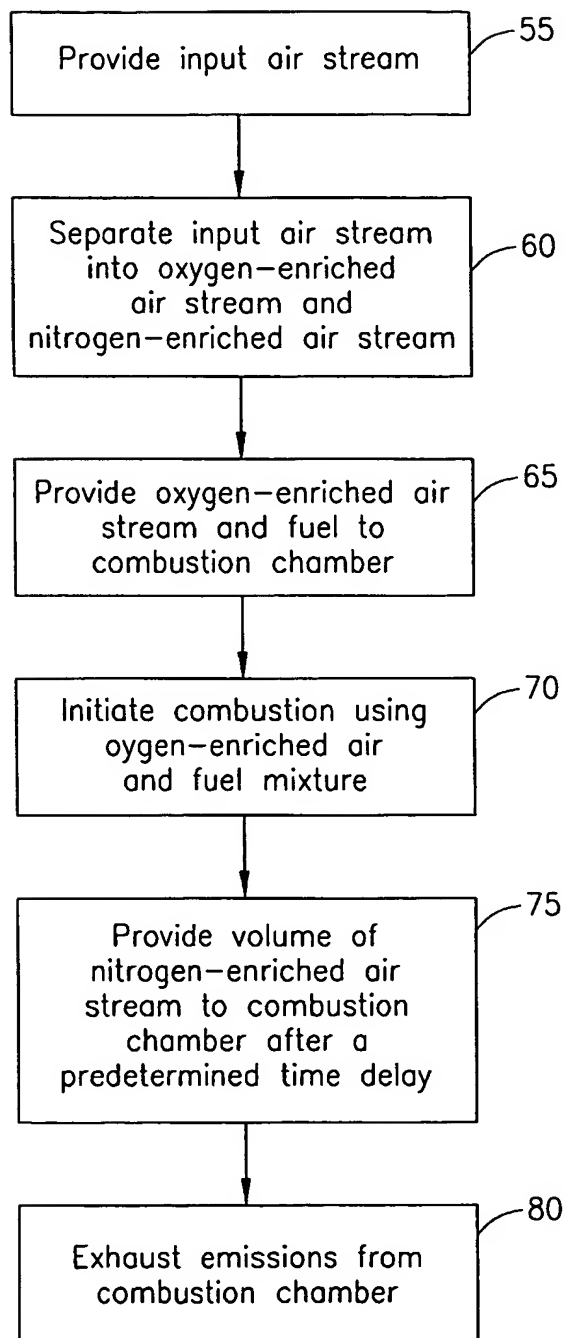


FIG. 2

3/3

*FIG. 3*

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 02/02168

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 F02M25/10 F02M25/12

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 F02M F02D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 649 517 A (SEKAR RAMANUJAM R ET AL) 22 July 1997 (1997-07-22)	7,14
A	column 16, line 10 - line 36; figure 1 ---	1
A	US 6 289 884 B1 (BLANDINO JOSEPH A ET AL) 18 September 2001 (2001-09-18)	1,7,14
	column 10, line 53 -column 11, line 8; figure 1 ---	
A	US 6 055 808 A (SEKAR RAMANUJAM R ET AL) 2 May 2000 (2000-05-02)	1,7,14
	column 12, line 1 - line 12; figure 1 ---	
A	US 5 640 845 A (SEKAR RAMANUJAM R ET AL) 24 June 1997 (1997-06-24)	1,7,14
	cited in the application column 2, line 38 -column 3, line 6; figure 1 ---	
	--- -/--	

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents :

- *A* document defining the general state of the art which is not considered to be of particular relevance
- *E* earlier document but published on or after the international filing date
- *L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- *O* document referring to an oral disclosure, use, exhibition or other means
- *P* document published prior to the international filing date but later than the priority date claimed

- *T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- *X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- *Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
- *&* document member of the same patent family

Date of the actual completion of the international search

7 October 2002

Date of mailing of the international search report

16/10/2002

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax (+31-70) 340-3016

Authorized officer

Raposo, J

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 02/02168

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	<p>US 5 636 619 A (SEKAR RAMANUJAM R ET AL) 10 June 1997 (1997-06-10) cited in the application column 2, line 51 -column 3, line 7; figure 1</p> <p>-----</p>	1,7,14

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/US 02/02168

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
US 5649517	A	22-07-1997	US 5636619 A US 5526641 A US 5640845 A	10-06-1997 18-06-1996 24-06-1997
US 6289884	B1	18-09-2001	DE 10127242 A1	21-02-2002
US 6055808	A	02-05-2000	AU 4705099 A WO 9967508 A1	10-01-2000 29-12-1999
US 5640845	A	24-06-1997	US 5526641 A US 5636619 A US 5649517 A	18-06-1996 10-06-1997 22-07-1997
US 5636619	A	10-06-1997	US 5526641 A US 5649517 A US 5640845 A	18-06-1996 22-07-1997 24-06-1997